E12-11-002: Proton Recoil Polarization in the ^{4}He(e,e'$\vec{p}$)^{3}H, ^{2}H(e,e'$\vec{p}$)n, and ^{1}H(e,e'$\vec{p}$) Reactions

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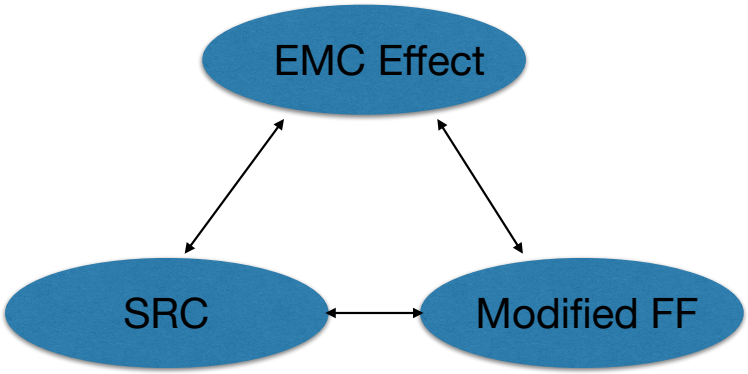
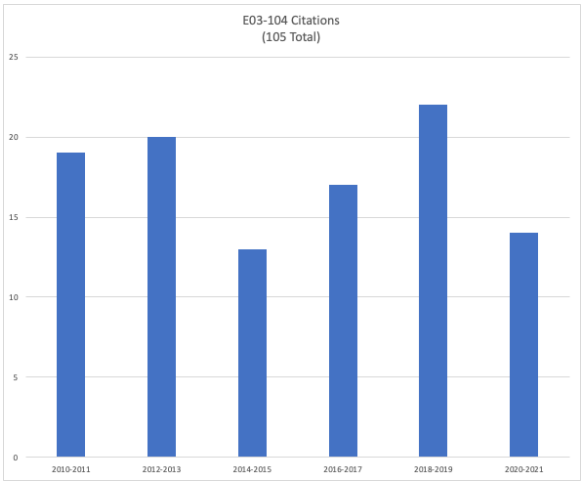
Motivation: What is the role of quarks in nuclear structure?

- This continues to be a topic of great interest!!
  - Arrington et al. - Prog. Part. Nucl. Phys. 67,898 (2012)
  - Hen et al. - Int. J. Mod. Phys. E 22,1330017 (2013)
  - Malace et al. - Int. J. Mod. Phys. E23,1430013 (2014)
  - Ciofi degli Atti - Phys. Rept. 590,1 (2015)
  - Hen et al. - Rev. Mod. Phys. E 23,1430013 (2017)
  - Guichon et al. - Prog. Part. Nucl. Phys. 100,262 (2018)
  - Cloët et al. - J. Phys. G 46,093001 (2019)
  - A.W. Thomas - arXiv: 1809.06622 (2020)
- What is the connection between the EMC effect and high momentum nucleons in nuclei?
- Related question: How is the nucleon modified in nuclei?



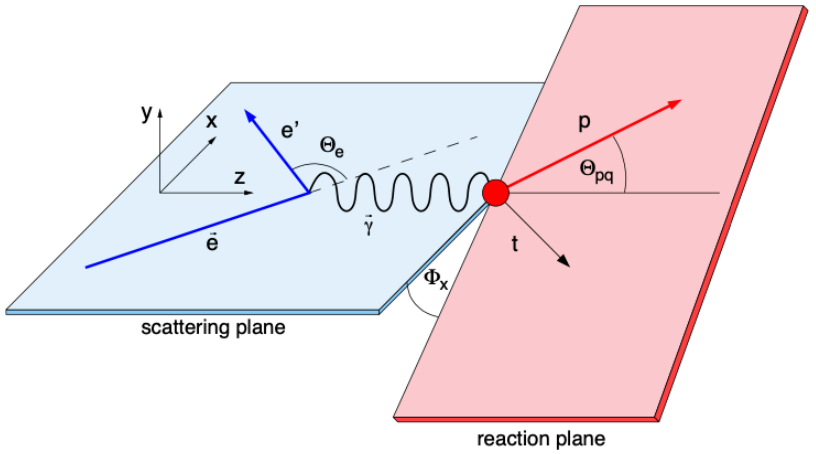


EMC Effect and SRC

- EMC: The valence quarks of a bound nucleon carry less momentum than those of free nucleons. Models that include nucleon modifications are needed to describe the data.
- The origin of these modifications is still unclear … do small modifications in a mean field (primarily) cause the changes? Are the modifications momentum-dependent?
- The connection between the EMC effect and SRC hints that the EMC effect may be caused (primarily) by high-momentum nucleons in correlated nucleon pairs.
- As we have seen, there is a program of experiments (approved and proposed) to study unpolarized, polarized, and isovector EMC effects, and to probe SRC in inclusive and semi-inclusive reactions.

Medium Modification of the Elastic EM Form Factors

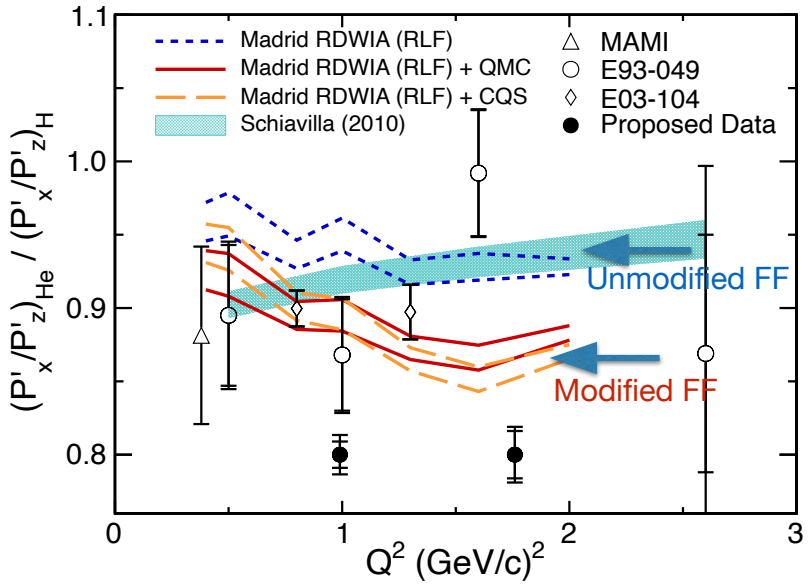
- The nucleon is modified in the nucleus. The EMC and related experiments test the consequence of that modification on structure functions.
- Models that describe those modifications also predict modifications of the elastic form factor. If one is modified, the other one should be, too.
- Our goal is to collect high precision data which will provide stringent tests of state-of-the-art models in a kinematic regime where medium modification effects are expected to be significant and where reaction mechanism effects are predicted to be small/ manageable.
- **"Our view is that the results of nuclear polarization experiments strongly indicate that medium effects do influence EM form factors. We eagerly await new experiments with improved precision and at larger values of p_{miss} which would confirm or rule out this interpretation." - Hen et al. (2017)**
- "[This experiment] will provide exciting new information on the origin of the EMC effect and could show conclusive evidence for in-medium modifications." - PAC37

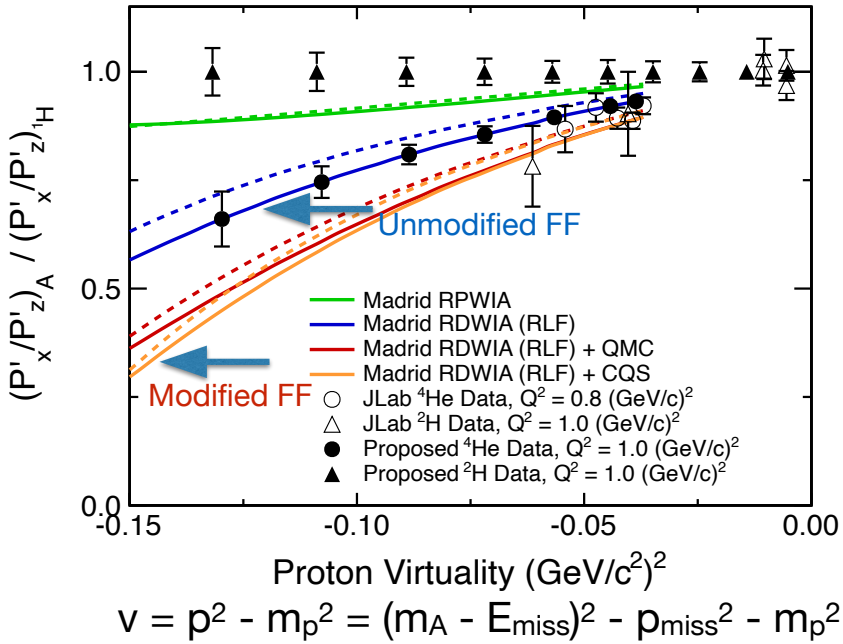


$$\frac{G_E}{G_M} = -\frac{P'_x}{P'_z} \cdot \frac{E_e + E_{e'}}{2m_p} \tan(\theta_e/2),$$

$$R = \frac{(P'_x/P'_z)_A}{(P'_x/P'_z)_{^1\mathrm{H}}}$$

Previous and Proposed Data





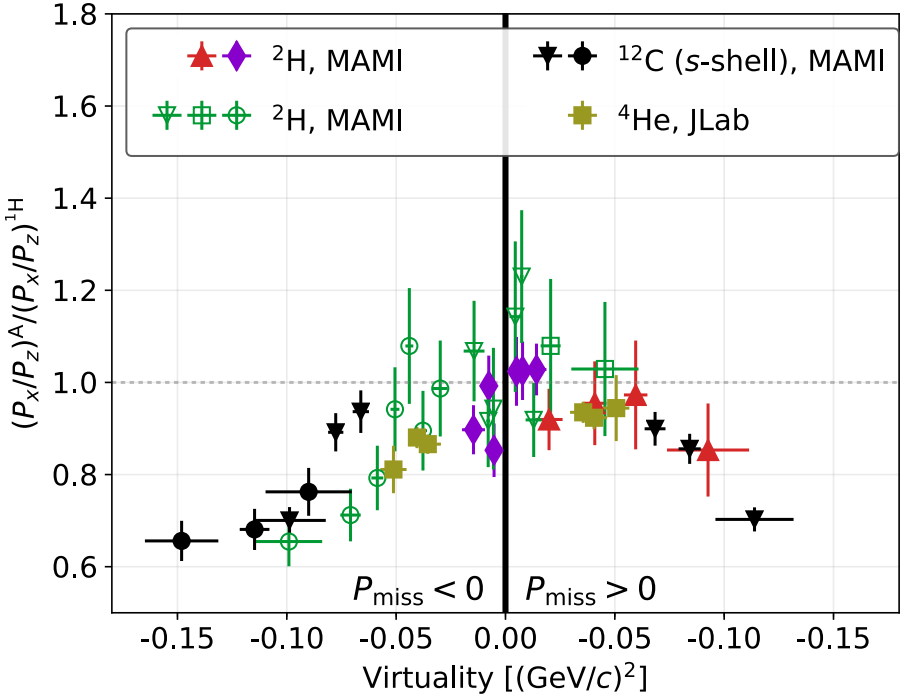
$v = p^2 - m_p^2 = (m_A - E_{miss})^2 - p_{miss}^2 - m_p^2$

Key Ideas:

1. **Measure with enough statistical precision to differentiate between and constrain models.**
2. **Measure the momentum/virtuality dependence.**
3. **Measure at as high a Q^2 as possible, while still maintaining high precision.**
4. **"Tagged" final state.**

MAMI Experiments

- Measurements at low Q^2, on several nuclei.
- Polarization double ratio appears largely independent of nucleus and momentum transfer, when comparisons are made at the same virtuality.
- Well described by models without FF modification - not surprising, given that effects are predicted to be small, and statistical uncertainties are in general large.
- Our experiment is unique, in that we will measure at higher Q^2, where medium effects are predicted to be larger and reaction mechanism effects are smaller.



Interpretation of the Data

- Measurements on ^{2}H (weakly bound) and ^{4}He (tightly bound).
- Nuclei which are well understood theoretically, but dense enough (^{4}He) to expect significant medium modification effects.
- P_{miss}/virtuality dependence gives information related to mean nuclear density vs. momentum of the bound nucleon interpretations.
- Super-ratio of polarization components, together with very favorable precession angle results in very small systematic uncertainties -> statistics limited.
- We will also measure the normal component of polarization, as a cross-check on our understanding of reaction mechanism effects. This was not a requirement in the original proposal, but we feel it is achievable and helpful.

Experiment Considerations

- The experiment uses the SHMS and HMS spectrometers in Hall C. The expected performance of the SHMS, as speculated in the original proposal, has now been realized. Important point -> The resolution is sufficient to isolate the ^{3}H final state in the ^{4}He portions of the experiment -> "tagged" final state.
- The Focal Plane Polarimeter (FPP) has already been used successfully in Gep-III in the HMS. For this experiment, we will make two modifications:
  - The FPP scattering analyzer will be re-designed to be optimal for the proton momenta being considered -> very similar to the way we did things in Hall A for Gep-I and Gep-II.
  - In order to measure P_y, we plan to make changes to the FPP wire chamber implementation.
    - Alter "perfect" alignment of UVX planes to remove left/right ambiguity issue at small scattering angles.
    - Add/change planes using existing spare chamber (required amplifier/discriminator cards and extra TDC channels are available).

Experiment Considerations

- We are updating the FPP GEANT3 simulations (which agree well with all previous FPP data) to GEANT4 -> this will help us to develop the ROOT/C++ analysis software now being used in Hall C.
- We are working on an AI/ML convolutional neural network approach to develop a better understanding of the instrumental asymmetries (resulting from physical misalignments in the FPP) -> it is a very natural problem for a ML approach. This will also help to optimize the effective analyzing power, based on optimal single track/multi track event selection, etc.
- Important point -> instrumental asymmetries are NOT a factor in the extraction of the principal P_x/P_l super ratio (the main focus of the experiment).
- The beam time request remains the same. All estimates used in the original proposal are very similar to actual values that we now know after SHMS/Hall C commissioning.

Summary

- Our goal is to collect high precision data which will provide stringent tests of state-of-the-art models in a kinematic regime where medium modification effects are expected to be significant and where reaction mechanism effects are predicted to be small/manageable.

- **“Our view is that the results of nuclear polarization experiments strongly indicate that medium effects do influence EM form factors. We eagerly await new experiments with improved precision and a larger values of p_{miss} which would confirm or rule out this interpretation.” - Hen et al. (2017)**

- This experiment is truly complementary to the program of experiments related to EMC effect and SRC.

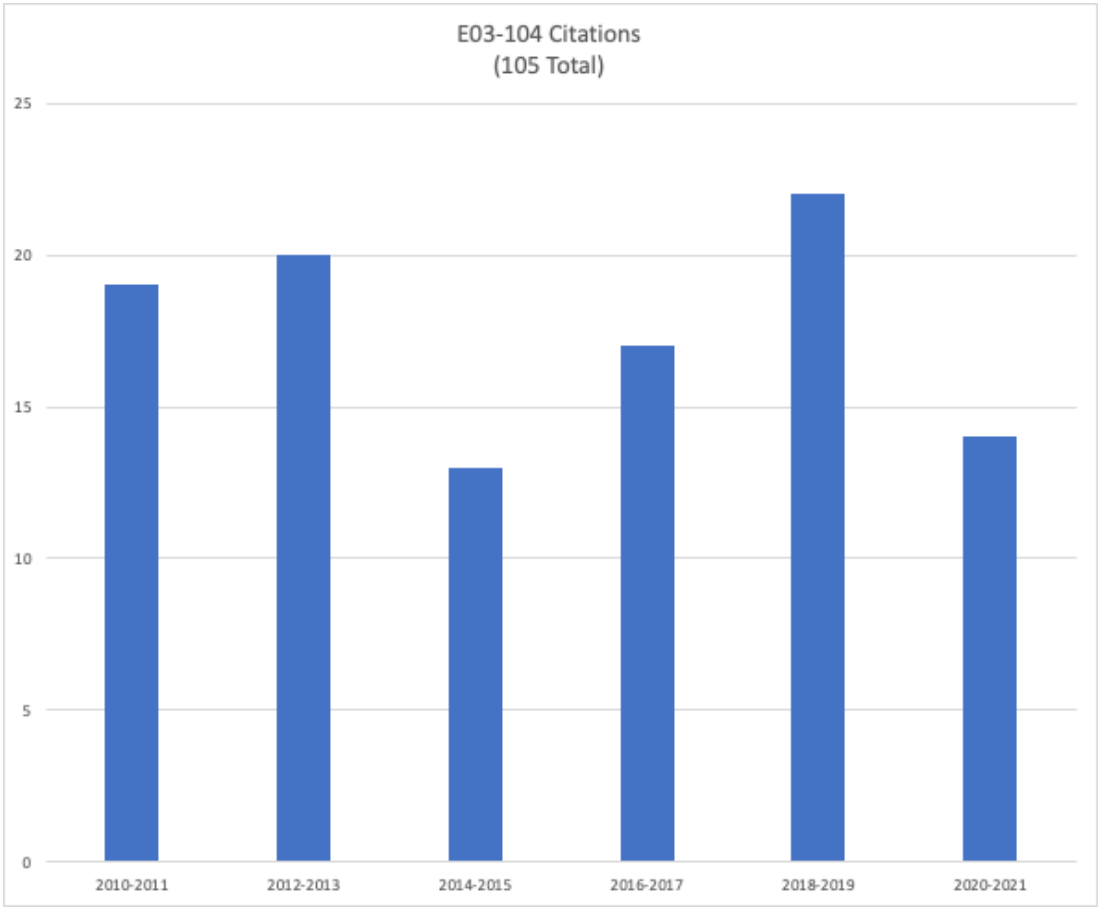
- There are no technical issues which would impede the experiment being carried out successfully in the near future (as scheduling allows).

- We are statistics limited - the original beam time request (37 days) was determined with a goal to be able to achieve statistical precision which allows one to distinguish between models, while still being at a level that is realistic in terms of scheduling.

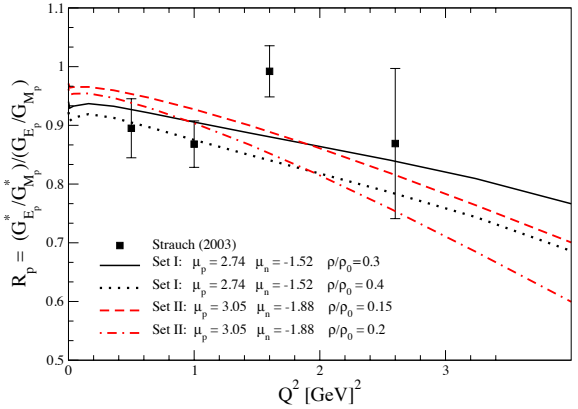
- It is our opinion that the scientific rating (B+) is not commensurate with the scientific motivation and interest in both the experimental and theoretical community.

Backup Slides

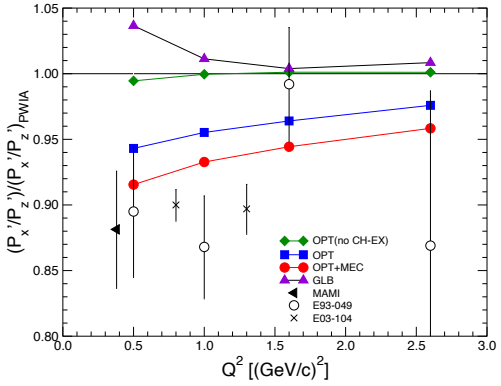
E03-104 Citations, by Year



Study of the in-medium nucleon electromagnetic form factors using a light-front nucleon wave function combined with the quark-meson coupling model

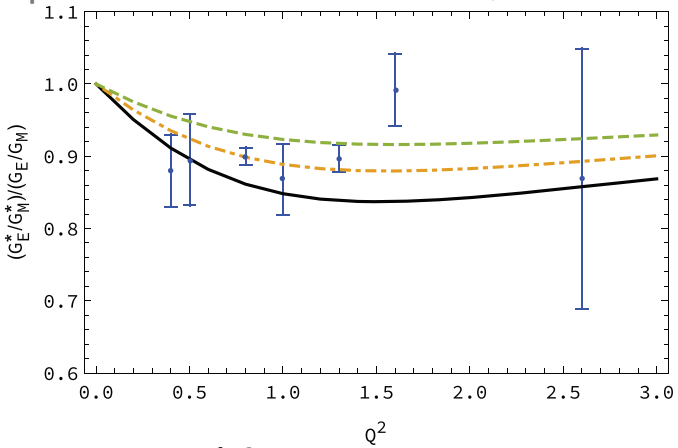


W.R.B.de Araújo, J.P.B.C.de Melo, K.Tsushima, Nuclear Physics A, 970, 325 (2018)



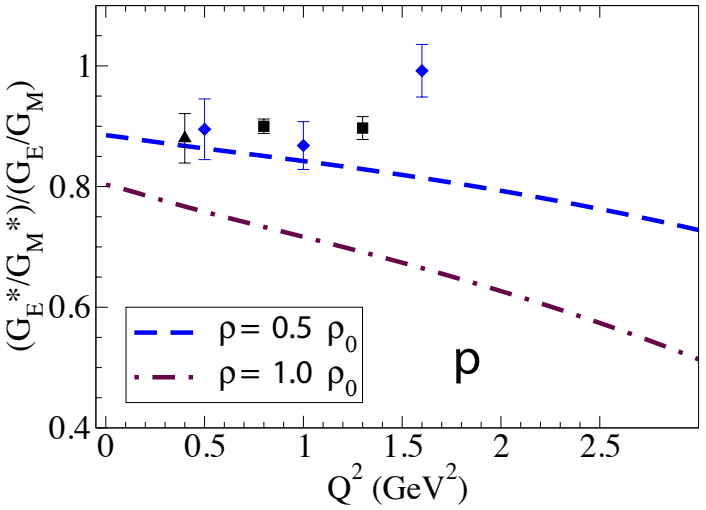
Reaction Model Studies

Properties of protons in nuclear medium with AdS/QCD model with a quadratic modified dilaton



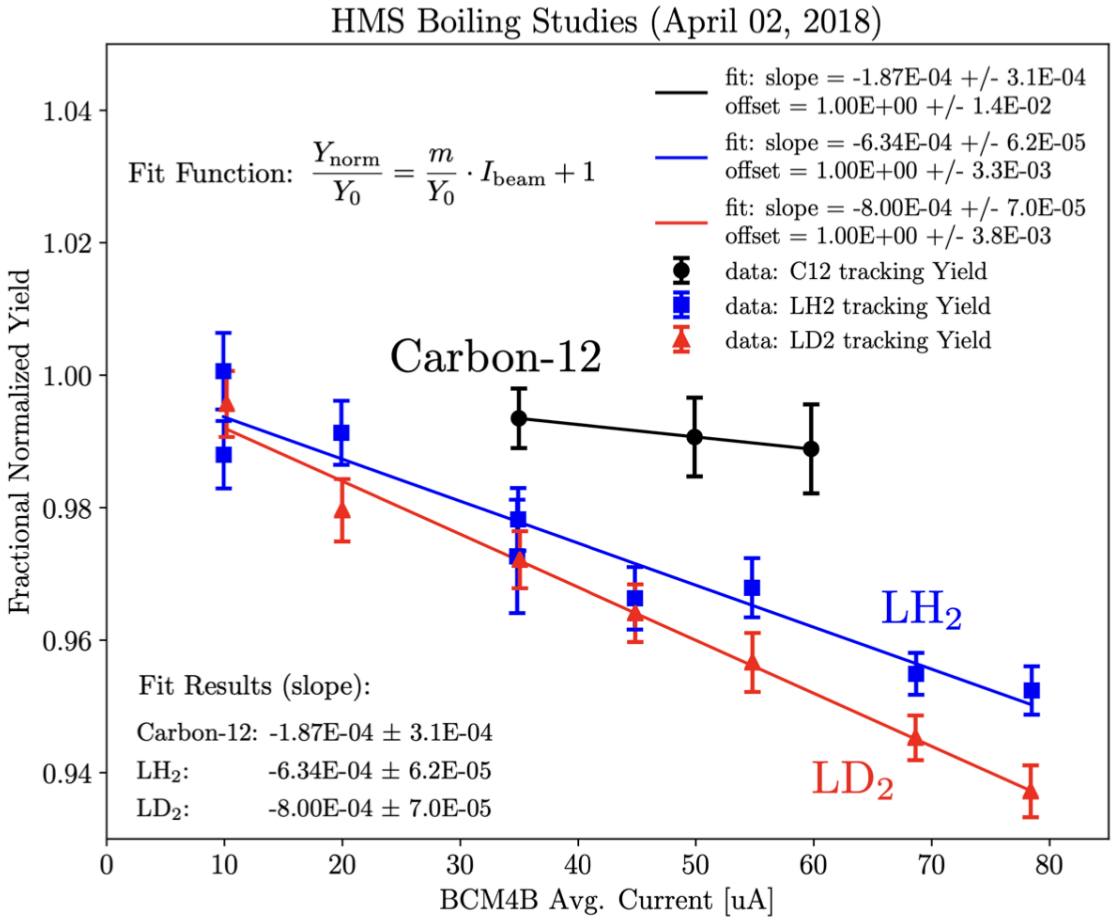
A. Vega, M.A. Martín Contreras, Eur. Phys. J. A 57, 113 (2021)

Octet baryon electromagnetic form factors in nuclear medium

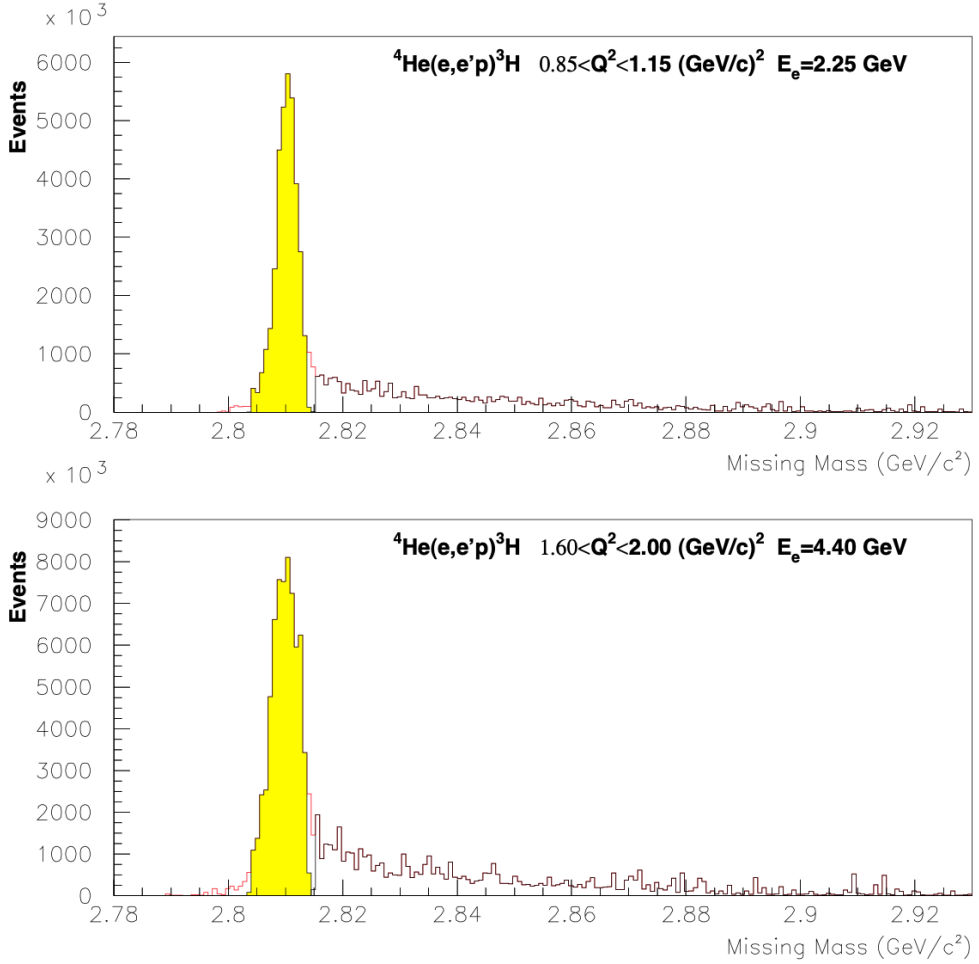


G. Ramalho, K. Tsushima, and A. W. Thomas, J. Phys. G 40, 015102 (2013)

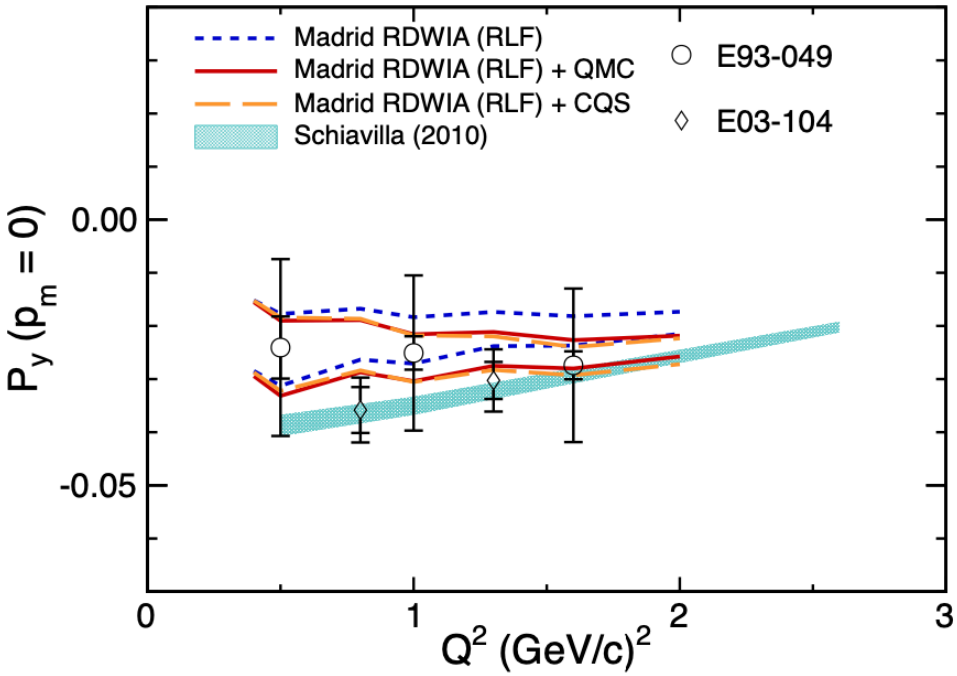
Target Boiling



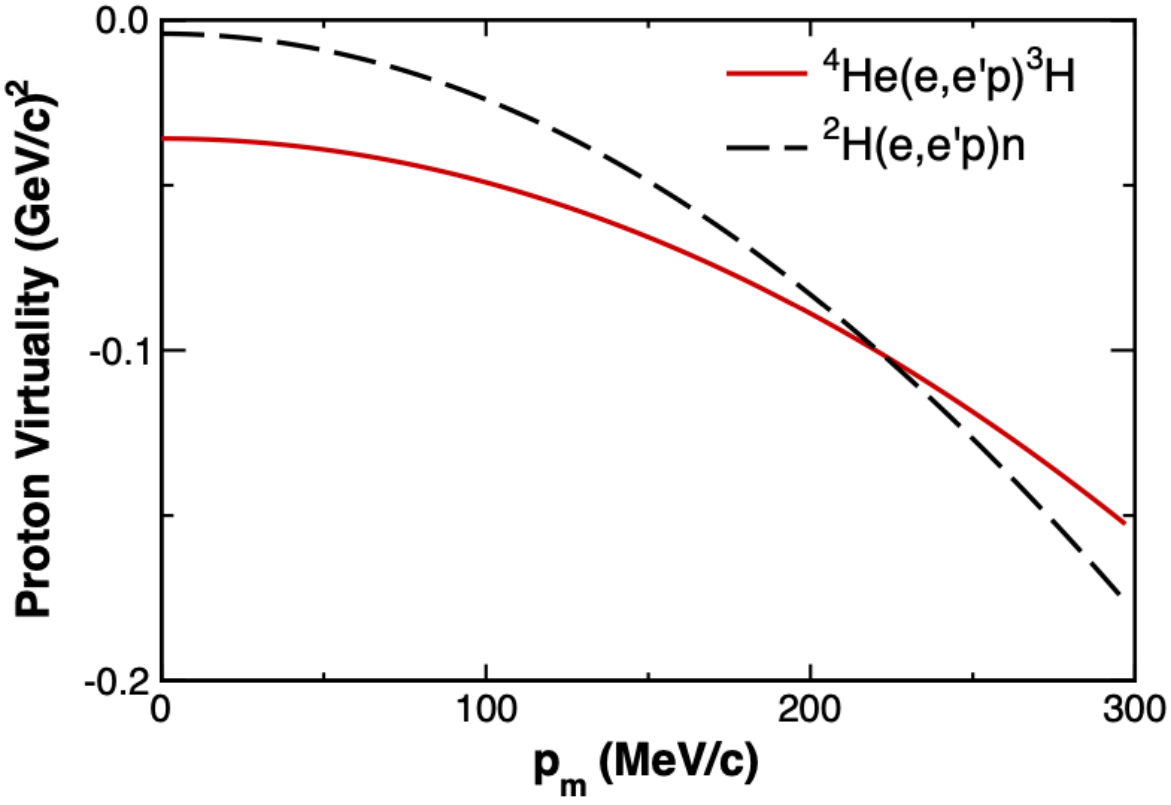
Missing Energy



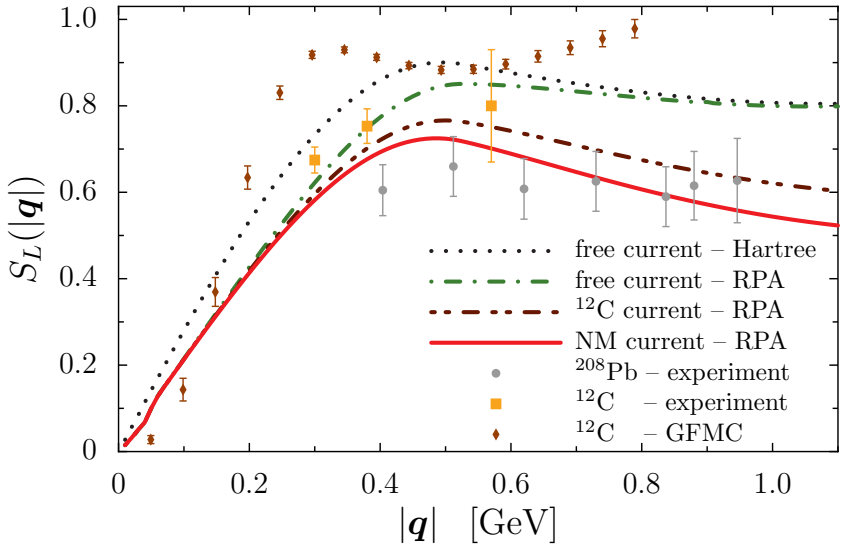
Normal Component of Polarization



Virtuality

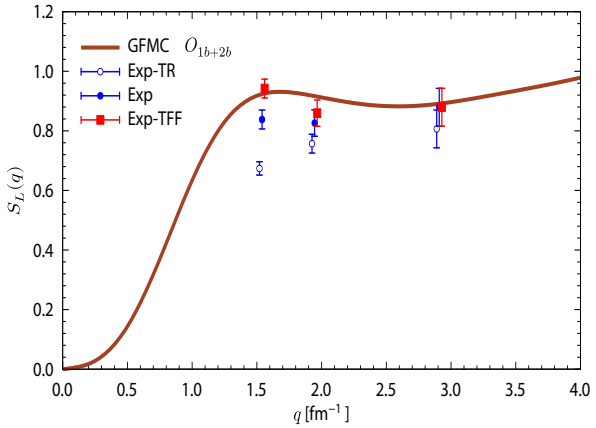

0.0
-0.1
-0.2
0
100
200
300
Proton Virtuality (GeV/c)²
p_m (MeV/c)
⁴He(e,e'p)³H
²H(e,e'p)n

Very different recent interpretations



"The observed quenching is directly associated with a softer F1p in medium."

Ian C. Cloët, Wolfgang Bentz, Anthony W. Thomas, Phys. Phys. Rev. Lett. 116, 032701 (2016)



12C

"The so-called quenching … emerges in this study as a result of initial-state correlations and final-state interactions."

A. Lovato, S. Gandolfi, J. Carlson, Steven C. Pieper, R. Schiavilla, Phys. Rev. Lett. 117, 082501 (2016)